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Transportation and Land Use Optimization: Land Use Utility Value Assessment Using Geographic Information Systems

by

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Transportation and Land Use Optimization: Land Use Utility Value Assessment using Geographic Information Systems[1,2]

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Abstract: The utility value of land use is a unit of measurement of the value of a specific land use zone in relation to the whole urban system. It is the potential socioeconomical output value of the land use of an area and it is defined according to concepts of accessibility level, socioeconomic level and spatial interactions. With the utility value, we are able to assign more efficiently transportation resources to land use zones and help solve transportation / land use optimization problems. A Geographic Information System is used to assign the utility value of land use in Shanghai. Results underline that the transportation / land use optimization in Shanghai is far from being efficient.
Key Words: Transportation, Land Use, Optimization, Geographic Information Systems (GIS), Utility Value, Shanghai.

Résumé: La valeur utilitaire de l'utilisation du sol est une unité de mesure de la valeur d'une zone d'utilisation du sol spécifique en relation avec l'ensemble du système urbain. Elle est la valeur socio-économique potentielle de l'utilisation du sol d'un espace et elle est définie par le niveau d'accessibilité, le niveau socio-économique, et les interactions spatiales. Avec la valeur utilitaire, il est possible d'assigner plus efficacement des ressources en transport à des zones d'utilisation du sol et ainsi aider a solutionner des problèmes d'optimisation de transport et d'utilisation du sol. Un Système d'Information Géographique est utilisé pour assigner la valeur utilitaire de l'utilisation du sol à Shanghai. Les résultats soulignent que l'optimisation des transports et de l'utilisation du sol à Shanghai est loin d'être efficace.
Mots clés: Transport, Utilisation du sol, Optimisation, Systèmes d'Information Géographique (SIG), Valeur utilitaire, Shanghai.

1. Geographic Information Systems in Transportation / Land Use Planning

There is a growing concern in urban planning to evaluate the impacts of decision making over the transportation / land use system (Jeffers, 1988). However, no decision should be taken without an evaluation of possible alternatives because of the complex transportation / land use processes involved. The evaluation of alternatives is defined as the decision thinking process and it relies on tools such as modelling and spatial analysis. Decision making involves actions dictated by decision thinking which requires numerous types of relevant information. Goals are endogenous to decision making while information is exogenous. Information must be compiled, standardized and synthesized in order to effectively represent the reality. This underlines the difference between data and information where information is what is relevant to the problem. Over the last two decades, new tools of geographic data management, spatial analysis and modelling have appeared in the form of geographic information systems (GIS). Those systems offer powerful means to manage and analyze the available information, and through modelling and analysis, produce new spatial information. The efficiency of those systems rests on their ability to store and manipulate large quantities of data so it can become information. Therefore, the GIS is a promising way to answer the requirements of the decision thinking and decision making processes, that is considering as much options as possible in order to find the one most suitable to a set of goals. Actually, transportation, land use and their relationships are the primary fields of information and concern in urban planning (Berechmann and Small, 1988; Webster, Bly and Paulley, 1988). In order to evaluate the interactions between transportation and land use, the assessment of a value to land use is needed. We propose a utility value of land use,

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which is a unit of measurement of the socioeconomical output of a specific land use zone in relation to the whole urban system. With this value, we are able to assign more efficiently transportation resources to land use zones and help solve transportation / land use optimization problems. We must keep in mind that sometimes the land use characteristics can be blurred by factors like the availability of data, its reliance and consistency.

Transportation / land use planning has, and continue to raise the following questions: 1) How to express transportation cost? In energy spend, in distance, for the environment, or in time? For instance, the choice of minimizing energy spend in transportation is quite incompatible with minimizing the travel time. The optimal would be minimizing energy spent, distance and travel time at the same time, but this would be a compromise between the choices. 2) How to optimize the relationships between transportation networks? Intermodality offers that possibility by giving transportation alternatives and a higher fluidity to movements. 3) What is the maximum spatial accumulation a zone can have? This underlines notions like economies of scale, diminishing returns, and maximal land use density. There is a limit to the spatial accumulation of interactions, transportation infrastructures and economic activities that can be set by planning. When this limit is reached, a land use zone loses part of its comparative advantages. 4) In which way transportation and land use have feedbacks on each other? Transportation changes certainly do not have a linear influence on land use. Do transportation changes preceed land use changes, or it is the opposite? Transportation infrastructures and land use are a long term process of spatial accumulation while interactions (movements) are far more flexible. 5) How externalities affect the relationships between transportation and land use? There is a growing concern on the environmental costs of spatial accumulation like air pollution and noise. 6) What is the required accessibility level for a land use zone, and by what mode? Each land use zone requires a capacity to convey movements in order to support the transportation demand of its economic activities.

Those questions represent current research concerns in optimizing transportation and land use. In this article, we will contribute to the discussion with the use a geographic information system to identify the utility level of land use in Shanghai. The objective is to develop the notion of utility value of land use and to contribute to the development of Geographic Information Modelling (GIM) methodologies in transportation/land use planning. The hypothesis is that an efficient urban system has the geographic distribution of its utility level in relation with the geographic distribution of land use types. This represents an efficient state of the process of transportation / land use optimization and spatial accumulation. In order to answer this hypothesis, we firstly present a brief overview of geographic information systems and their relevance in transportation / land use planning. Secondly, we develop the notion of utility value of land use. Thirdly, we update the concept of transportation / land use optimization considering the notion of the utility value of land use. And lastly, an assessment of the utility value to the land use of Shanghai is undertaken.

A geographic information system is a database system which deals with geographic data. Most geographic information systems include four components (Bracken and Webster, 1990): 1) An information input system that collects and processes spatial information such as maps, remote sensing images and digital input. 2) An information storage and retrieval system that organizes spatial information in a structured topological form which can be retrieved on queries for manipulation, analysis and display. This system must have the capacity to be updated and maintained. 3) An information manipulation and analysis system that performs tasks such as changing the form of the information through aggregation rules and modelling. 4) A display system that is able of displaying selected portions of the spatial database in the form of reports or cartographic results. The third component of a GIS (data manipulation and modelling) is the main focus of this article.

Table 1.1: Types of Geographic Information Modelling (GIM)

GIM Type	Example of tasks
Static, deterministic modelling	Reclassification, Interpolation, Arithmetic and Logical Manipulation
Simulation modelling	Transportation Model, Land Use Model, Spatial Interaction Model
Modelling interactions between systems	Transportation/Land Use Model
Modelling in a decision analysis environment	Expert System

According to Dangermond (1987), Geographic Information Modelling (GIM) is a methodology that have four levels of ascending complexity (see table 1.1): 1) Static, deterministic modelling. This level involves simple modelling like reclassification, interpolation, arithmetic and logical manipulation of geographical data. 2) Simulation modelling. These models try to simulate the behaviour of a system by quantifying the relations between a set of variables which are believed to represent the state of a system. Land use models are a good example of that type of attempt. 3) Modelling the interactions between systems. It is an attempt to join separate models that deals with specific systems in order to simulate a meta-system. Transportation/Land Use models try to simulate such a meta-system. 4) Modelling in a decision analysis environment. This requires the design of an environment in which models are used for decision thinking and decision making. Expert Systems (ES) are a potential set of tools and methodologies to assist the planner in complex decision thinking and making situations like transportation (Rodrigue and Comtois, 1991).

The litterature on transportation / land use planning is quite numerous, and it is not the intention here to make a review of that litterature. Notions of transportation and land use planning in a wide variety of situations can be found for example in Black (1981), Blunden and Black (1984), Fabos (1985), Pryor (1987) and Dimitriou and Banjo (1990). Geographic information systems offer a powerful tool for transportation / land use planning. The main factor favouring GIS is their ability to handle large amount of geographical information. That is precisely the kind of data transportation / land use models deal with. Other factors are GIM and cartographic display capabilities. However, the GIS technology applied to transportation / land use planning is nearly inexistant, principally for two reasons: 1) It requires geographic information modelling (GIM) methodologies that are not yet been developed (Dangermond, 1987). Existing GIS packages are still poor modelling tools but important breakthrough have been attained over the last decade (see IGIS and EGIS proceedings, 1987, 1990); 2) The relationships between transportation and land use have been only partly understood. There still is no reliable theory that simulate effectively transportation / land use systems (Berechmann and Small, 1988). The overall problem is a lack of theories, procedures and methodologies more than a lack of hardwares and to some extent softwares. The use of the information implemented in a GIS to the purpose of transportation / land use planning can be conceived at three levels of planning, strategic, tactical and operational. However, we must underline that the distinction between the planning levels is often not clear, particularly between strategic and tactical planning.

1.1 Strategic Planning

Strategic planning involves long term decision thinking and decision making over land use. This is the level where global urban planning takes its roots by the assessment of the territorial use of the urban space in order to respond more to political needs than an optimal search. Political needs can vary rapidly, so the necessity of an adaptable planning environment is even more required. This is why this planning level often requires more qualitative than quantitative information. The use of a GIS at this level of planning presents few difficulties because of its capability to deal with qualitative and quantitative information on a wide range of scenarios. The information gathering is easy particularly, because the scale of analysis is included in a limited number of geographical entities and because the data is often required for only one period in time. Strategic planning is often a "before" and "after" planning process starting from an initial situation through a new state corresponding to a scenario. In that context, planners have two alternatives: 1) With a planned desired state of the urban system, trying to assess the strategies

to attain that state. This is an inductive approach. 2) With fixed planning strategies, trying to find the resulting state of the system. This is a deductive approach. The use of a GIS in strategic transportation / land use planning offers a perspective that helps planners to deal with problems like: 1) The geographic definition and context of the planning area. A GIS can be used to define zones over which the decision thinking and decision making processes occur. The boundaries can be imposed by political aspects or can be estimated by spatial models like distance decay or potential mapping. The geographical characteristics of the urban space like hydrography and topography can be implemented in a GIS for the purpose of reference and constraints on the transportation / land use system. 2) The assignation of main transportation infrastructures. A GIS offers a tool to design transportation networks along corridors that can be used to maximize the accessibility of an area by placing roads were they will cover as much space as possible or to cover all designated areas. 3) The assignation of residential areas and economic infrastructures. A GIS can help design the general land use pattern of an urban system with criteria like the distance from transportation facilities, employment sources, the density of the land use types and the availability of land. 4) The evaluation of spatial interactions at a regional scale through modelling (van Est and Sliepen, 1990). The objective is to spatially disaggregate the transportation demand and supply. 5) Calculate the accessibility levels of the whole planning area in order to identify zones that require an higher accessibility level.

1.2 Tactical Planning

This level involves urban planning over an average period of time, that is from 1 to 2 years. It involves decisions affecting specific types of land use and transportation infrastructures. The required information is often more detailed and needed for two or more periods in time. Most available transportation/land use models are built to work at that scale of urban planning (Berechman and Small, 1988; Webster, Bly and Paulley, 1988). The existing GIS tools are adaptable with data over time and the use of a GIS for this level of planning is highly recommendable. However, time series can create a large number of maps for the same attribute that can be quite difficult to handle. A planner using a GIS for tactical planning can: 1) Evaluate the impact of the design of specific land use zones according to the proximity of transportation infrastructures and to estimate the area of influence of those zones (Comtois and Rodrigue, 1991). 2) Plan the local transportation network with the overlay of transportation networks maps to find the most convenient intermodal points for passengers and freight and find by modelling specific accessibility levels. 3) Evaluate through models the spatial interactions of passengers and freight to plan the transportation network according to the spatial distribution of movements. This is optimizing transportation supply with transportation demand which is a part of the transportation / land use optimization process. 4) Build a comprehensive geographical database of physical and socioeconomical features and constraints that can be used for decision making and decision thinking reference.

1.3 Operational Planning

Operational planning is the lowest level of planning. It involves decisions over the day to day use of the transportation / land use system and its logistics. In our context, it is more a transportation system planning than a land use planning because land use changes are often occurring over a long period of time. Therefore, the operational level have few relevance in land use planning. This level use a great amount of information over several periods in time like the hourly traffic flow through a road segment. GIS are not currently designed to deal with operational planning but they still can be used as a source of information. Spatially referenced urban information systems (a type of GIS used urban planning) have some applicability to operational planning by giving the state of several urban infrastructures like bus stops, metro stations, road arterials, etc... Examples of transportation operational planning are bus route scheduling, traffic lights time-table and delivery trucks scheduling.

1.4 Relevance of GIS in Land Use Planning

An efficient urban planning process should consider those three levels of planning and should begin at the strategic level. When the strategic goals are identified, the emphasis drop to the tactical level where more local problems are dealt with. The operational level is used to answer local and specific problems of the transportation system. The use of each planning level depends on the goals and in some cases only one planning level is required. For instance, with a previously given strategic planning goal, like the construction of a ring road to decongest the central city, only tactical planning is needed for the location of that road, but operational planning should be used if there is a need to assess infrastructures like traffic lights or bus stops.

Table 1.2: GIS and Transportation / Land Use Planning

Aspect \ Level	Strategic	Tactical	Operational
Time Period	Long (+2 years)	Average (1-2 years)	Short (<1 years)
Information Gathering	Average	Difficult	Very Difficult
Data Requirement	Low	High	Very High
GIS Applicability	High	Average	Low
GIS Complexity	Average / High	High	Very High
GIS Utility	Very High	High	Low

Table 1.2 shows the weaknesses of a GIS in operational planning, and in some measure in tactical planning The major weakness of a GIS in transportation / land use planning is that very few GIS can perform even the simplest network analysis (like the gamma index). This is peculiar since vector based digitizing and storage is easily done, but it is only used for polygon definition, not network definition. The integration of a GIS and a software that deals with tactical and operational planning like transportation networks analysis (Emme/2) and multimodal route optimization (Stan) would provide a powerful environment for transportation / land use planning and optimization. However, we are still far from geographic information modelling in a decision analysis environment.

Considering the current weaknesses of GIS and GIM, we use those methodologies in strategic and tactical planning through the assessment of an utility value to the land use of Shanghai. That methodology is static, deterministic modelling because it use a simple arithmetic manipulation of geographical data represented as map layers. However, we will show how the utility level can be used in simulation modelling of land use and in modelling the interactions between transportation and land use.

2. Land Use: Utility Value vs Land Rent Value

Land use is the accumulation on an area of interactions, transportation infrastructures, economic activities and population. Even if the variables representing land use are discrete, land use is strictly a qualitative term. In classic notions of land use planning and economic geography, the assessment of a quantitative value to land use was done using the land rent theory, and planning was done according to rent value. This notion is one of the oldest modern geographical concept (Von Thünen, 1821). According to this theory, each type of land use occupies areas where land rent corresponds to the value that it is able to pay. The basic assumption of land rent theory is that each type of land use maximize its welfare (Alonso, 1960; Muth, 1969), so:

$$Max : u = u[z, q, s] \tag{1}$$

Where: u = Welfare.
z = Composite good.
q = Quantity of land.
s = Distance from the city centre.

Equation 1 is subject to a set of constraints like transportation costs and the available quantity of land. This assumption is still the base of recent developments of land rent theory such as the consumption theory of land rent (Thrall, 1987), but it is presently argued that the distance from the city centre plays a less important part in the assessment of land rent value. The polycentric state of a number of metropolitan areas underline that problem (Huth, 1983). Therefore, land rent is the perceived economical value of space. Without denying the relevance of the land rent theory, we stress the need to evaluate the utility value of land use in terms of what it is worth for the performance of the urban system and not for the owners. The performance of an urban system is an abstract concept, but we could express it by a low congestion level, by an equitable distribution of economic activities and of spatial accumulation, and by a structured pattern of movements of all modes. The utility value is the potential

socioeconomical output value of the land use of an area. It is defined according to concepts of accessibility level, socioeconomical level and spatial interaction. Accessibility defines the capacity of an area to convey movements of several modes, more simply the transport supply. It is also expressed by the accessibility to intermodal infrastructures. Socioeconomical value is the value of the infrastructures built on an area and the productivity level of that area. An infrastructure can have a monetary, a functional and a cultural value. For example, some residential areas can have a high land rent because of factors like prestige and history, but the utility value of those same residential areas can be low. Spatial interactions are the set of movements of people, goods and information between spatial entities.

The land rent value of an area is quite independent of the infrastructures built on it, but the built infrastructures are directly related to the land rent value. The whole theory of urban rent value is based upon that fact (Alonso, 1960). On the contrary, the utility value of an area is directly related to the nature of the built infrastructures because it partly represents the economic output of those infrastructures. The more a land use zone have an high utility value, the more that zone is important in the performance of the overall urban system. With the same land rent, a highly productive industrial facility has a higher utility value than a less productive one. It is similar to the land rent value of an airport compared with its utility value to the whole urban area because the infrastructures of an airport are more expensive than the land they are built on in term of construction, maintenance and operation. Also, the economic output of an airport for an urban system is very high. For the tertiary and quaternary sectors, their high level of productivity place them at the highest utility value.

The basic assumption of the utility value theory, like the land rent theory, is that each type of land use tends to maximize its utility level. Both notions partly depend on the relative position of a land use zone in the whole urban area. The relative position is based on distance such as from downtown (aspect less significant than before), from transportation facilities (modal and intermodal), or from other areas. Each type of land use occupies areas where the utility level corresponds to the required levels of territorial accessibility, so the utility value is highly related to the density of land use. The utility value of zone i (U_i) is defined by:

$$U_i = v\, u_i \tag{2}$$

where the utility level u_i is defined by:

$$u_i = f\{A_i\ ,\ E_i\ ,\ T_i\} \tag{3}$$

where: v = Value by level of utility.
u_i = Utility level of zone i.
A_i = Accessibility level of zone i.
E_i = Socioeconomic level of zone i.
T_i = Interaction level of zone i.

The utility level of zone i is a function of accessibility, socioeconomic and interaction levels. The more a zone will have an high density of those concepts, the higher will be its utility value. Equation 2 stresses the difficulty in giving a monetary value by level of utility. How to give a value to utility? Is this value in dollar or in economic output? Those questions raise complex notions of land economics that have not yet been answered. Therefore the value by level of utility will not be discussed in this article. The utility value is proportional to the utility level, so we can remove v from equation 2:

$$U_i = u_i \because U_i \propto u_i \tag{4}$$

Therefore, for the remaining of this paper the utility value of land use will be addressed as the utility level because we cannot give a value by level of utility. The utility level considers both the demand and the supply of the transportation system. If the difference between the interaction level and the territorial accessibility level of a zone is negative, there will be a tendency towards a higher density of land use (spatial accumulation) because there is a potential for spatial accumulation and economies of agglomeration. On the contrary, if the interaction level exceeds

the territorial accessibility level, there are congestion costs that initiate a loss of density process. External costs overcome the advantages of the location. Equation 3 shows that the utility level is an overlay of specific utility levels related to accessibility, socioeconomic and interaction variables. Geographic information systems offer tools to handle that problem in the form of map overlays. Considering the difficulties of assessing a discrete quantitative utility level, the use of an ordinal utility level is more recommended. In overlay analysis, the utility level is defined by a weighted sum of maps:

$$U_i = \sum_x M_i^x \, w^x \qquad \sum_x w^x = 1 \tag{5}$$

where: M_i^x = Utility level at area i for attribute map x.
w^x = Weight of attribute map x on the overall utility level.

Examples of maps overlays could be the overlay of population density, employment density and of road accessibility maps, and several other maps related to accessibility, socioeconomic and interaction levels. The result, an utility level map, can be used in the process of transportation / land use optimization.

The utility level can be a very flexible concept depending on what planners view as useful and less useful. For instance, some authorities might view the same area from different point of view. Environmentalists may assign an area an high utility level because it contains some rare ecosystem while an industrial development board could assign the same area a high utility level because of its location relative to transportation infrastructures. Therefore utility is viewed as a purpose.

3. Transportation / Land Use Optimization

In existing urban areas a great deal of resources (human, capital and infrastructures) and energy are spent in maintaining an improving movements between economic entities. With the raising costs of energy and resources, planners look upon means to lessen the costs of movements generated by economic activities. Optimizing transportation and land use is such a mean. Transportation / land use interrelationships occur in a complex urban system where an optimal level cannot be reached because the required changes to attain the optimal would be too important considering constraints like limited budgets and existing spatial patterns. The optimal is a theoretical spatial pattern that the existing spatial pattern must tend to in order to optimize transportation and land use. The optimal spatial pattern would be a "perfect" city were there are no congestion, an equitable distribution of economic activities and of spatial accumulation and a structured pattern of movements. This is unrealistic and we suggest that reaching a functional level is not necessary done by aiming at an optimal one. The main objective of the decision thinking process is to find a functional level of the transportation / land use system given a set of constraints that cannot be bypassed. Optimization is considered as a set of process to attain a functional state for an urban system, not a perfect one. Constraints are of three general types: spatial, infrastructural and social. Spatial constraints are related to the geographic distribution of infrastructures and land use pattern. Infrastrastructural constraints are the capacity of existing transportation infrastructures and the density of land use zones. Social constraints are the most difficult to express. Some locations have an high historical and cultural significance where a value is very difficult to assess. Existing planning strategies are a social constraint in the sense that most of the time they do not consider the transportation / land use optimization has an explicit goal.

Over the past, transportation models have been used by transportation planners to solve transportation problems which considered land use as given. It has been the same for land use planning that considered the transportation system as given. At the beginning of the 80s the emphasis has shifted over the interrelationships between transportation and land use that is considered as a whole system instead of two separate ones (Los, 1979). We suggest that the overall objective of transportation / land use optimization is to minimise the cost of the movements for all modes between land uses and to maximize the utility level of land uses by methodologies already available in operations research (Bronson, 1982) or new ones. This seems simplistic but implies several complex planning processes. Thus transportation / land use optimization considers first, the minimization of the transportation

costs (C) (Wilson and al., 1981):

$$Min : C = \sum_i \sum_j \sum_k c_{ij}^k \, T_{ij}^k \tag{6}$$

subject to

$$\begin{aligned} \sum_j \sum_k T_{ij}^k &= O_i^k \\ \sum_i \sum_k T_{ij}^k &= D_j^k \end{aligned} \tag{7}$$

$$T_{ij}^k \geq 0 \; (\forall \; i, j, k) \tag{8}$$

where: T_{ij}^k = Spatial interaction of mode k between zones i and j.
c_{ij}^k = Transportation cost of mode k between zones i and j.
O_i^k = Net trips of mode k leaving zone i.
D_i^k = Net trips of mode k arriving a zone i.

and second, the maximization of the utility level of land use (U):

$$Max : U = \sum_i v \, u_i \tag{9}$$

subject to

$$u_i \leq M_i \tag{10}$$

where: u_i = Utility level of zone i.
v = Value by level of utility.
M_i = Maximum utility level a zone i can have.

Equations 6 and 9 enable us to underline the main link in the process of optimizing transportation and land use, that is accessibility. From the planner's point of view, raising the transportation supply of a zone will lower the transportation cost (minimizing C) and raise the utility level (maximizing U). The relationship between transportation and land use is not that simple considering the important feedbacks of congestion costs and externalities like environmental degradation and circulation accidents. Joining equation 6 and equation 9 and including the concept of externalities will produce the general transportation / land use optimization (maximize TLU) equation, so:

$$Max : TLU = Min : C \cup Max : U \cup Min : X \tag{11}$$

Where X are the external costs, or externalities. These three functions are mathematically easy to solve separately, but are conceptually difficult, if not impossible to jointly apply to transportation / land use planning. Facing that problem, a strategy often employed is to optimize only one part of equation 11. For instance transportation planners only attempt to minimize the transportation costs while land use planners try to maximize the utility level of land use (most often according to the land rent theory). Externalities are often ignored in the planning process.

Equation 11 does not identify the level of relationship between transportation and land use ($Max : TLU$). Our contribution to the development of transportation / land use optimization methodologies is to propose that the state of transportation / land use optimization can be measured by the degree of relationship between the utility level and the land use type. A simple statistical method, the contingency coefficient, can measure the level of relationship

between the utility level and land use. The contingency coefficient is a measure of association between two non parametric variables (Norusis, 1983). A contingency coefficient between utility level u and land use L ($CC(u,L)$) is expressed by:

$$CC(u,L) = \sqrt{\frac{\chi^2(u,L)}{\chi^2(u,L) + N}} \tag{12}$$

and where:

$$\chi^2(u,L) = \sum_{\forall u} \sum_{\forall L} \frac{\left(O(u,L) - E(u,L)\right)^2}{E(u,L)} \tag{13}$$

where: $\chi^2(u,L)$ = chi square statistic between utility level u and land use L.
$O(u,L)$ = observed surface by utility level u and land use L.
$E(u,L)$ = expected surface by utility level u and land use L.
N = total surface.

The expected surface by utility level and land use assume that this surface is uniformly distributed. The more the contingency coefficient tend to 1, the more the utility level is associated with land use. This express the degree of transportation / land use optimization. However, it is not likely that any urban system will have a value of the coefficient somewhere near 1. The next section will apply the developed methodology to Shanghai.

4. Utility Level Assessment to the Land Use of Shanghai

Shanghai is the largest city, the most important port and the hearth of the industrial production of China. The city is experiencing population and industrial relocation, functional land use changes, a formal and informal state of the transportation system and an increasing importance of the international trade in the economic production (Comtois and Rodrigue, 1991; Comtois, 1989). The complexity of the urban system of Shanghai requires efficient tools to help the decision thinking process to have a right overview of the situation. Geographic information systems provide a geographical database system that could help the management of available information on Shanghai and represent more efficiently the state of the system. To assess an utility level to land use in Shanghai, several variables were used. Each variable represents a layer of information in a GIS. This procedure is a simple arithmetic operation (see equation 5) representing the first level of complexity of Geographic Information Modelling (GIM).

4.1 Map Layers and Weights

Equation 3 has defined three types of variables to assign an utility level to land use: accessibility, socioeconomic and interaction levels. In a GIS, each variable is represented as a map layer with a class ranging from 1 to 10, were 10 is the lowest value. For the first type of variables, the accessibility level, four map layers were digitized. On the first layer, the road transportation network of Shanghai was digitized and a class was assigned to each type of road. The class range from 1 to 4, were class 1 represents the primary roads and 4 represents small urban roads of less than 4 lanes. The transportation network was digitized as vector, but vectors do not have a width. A 1 km large corridor was therefore calculated for class 1 roads and a 0.5 km corridor for class 2 roads. Class 3 and 4 road were discarded. The result is a map layer of the general road accessibility in Shanghai. The second map layer representing accessibility is a corridor of 0.5 km starting from the shore of important waterways such as the Wusong and the Huangpu rivers. The third layer is concentric circle map representing the distance from the central area of Shanghai as defined by the planning authorities. Even if Shanghai does not have a central business district, there is a central area that have an important concentration of commercial activities along road axes like Nanjing Lu. The first circle as a radius of 1 km that encompass the whole central area. The following circles have a radius gradient of 3 km. The fourth layer is a concentric circle map representing the distance from the Hongqiao

international airport that was recently renovated. Accessibility levels of the distance from city center and distance from airport maps give an high accessibility level to a corridor between the downtown and the international airport.

For the second type of variables, the economic level, two map layers were digitized. The first layer represents a map of the density of population per square kilometres. This map is the result a contouring procedure based on the population density for the economic zones of Shanghai. They are over 100 economic zones in Shanghai. A centroid was assigned for each economic zone and contouring was done according so. The second layer represents a map of density of employment in the industrial sector that was obtained using the same procedure as the population density layer.

For the third type of variables, the interaction level, three map layers were digitized. The first layer is the attraction for persons by transit for each economic zone. The attraction is the sum of all the movements going in an economic zone. Interaction layers were obtained using the same procedure than economic layers. The second and the third layers are the attraction for persons by bicycle and by car. Table 4.1 presents the map layers used for the assessment of an utility level of land use in Shanghai.

Table 4.1 : Map Layers Used to Assign an Utility Level to Land Use in Shanghai

Accessibility Layers	Economic Layers	Interaction Layers
Road accessibility (A^1)	Density of population (E^1)	Attraction by transit (T^1)
Waterway accessibility (A^2)	Density of employment (E^2)	Attraction by bicycle (T^2)
Distance from urban centre (A^3)		Attraction by car (T^3)
Distance from airport (A^4)		

The map layers used in our analysis represent a transportation infrastructure utility level, which is not the only type of utility level that could be assessed. No social variable is used except in some way the density of population. Equation 5 requires the use of weights in the assessment of an utility level to land use. As a part of a map overlay procedure, each variable is given a weight according to a model of weight distribution by variable. In this study, we limit ourselves to three models of weight distribution that are presented on table 4.2 and figure 4.1.

Figure 4.1: Distribution of Weights by Map Layer for Three Models

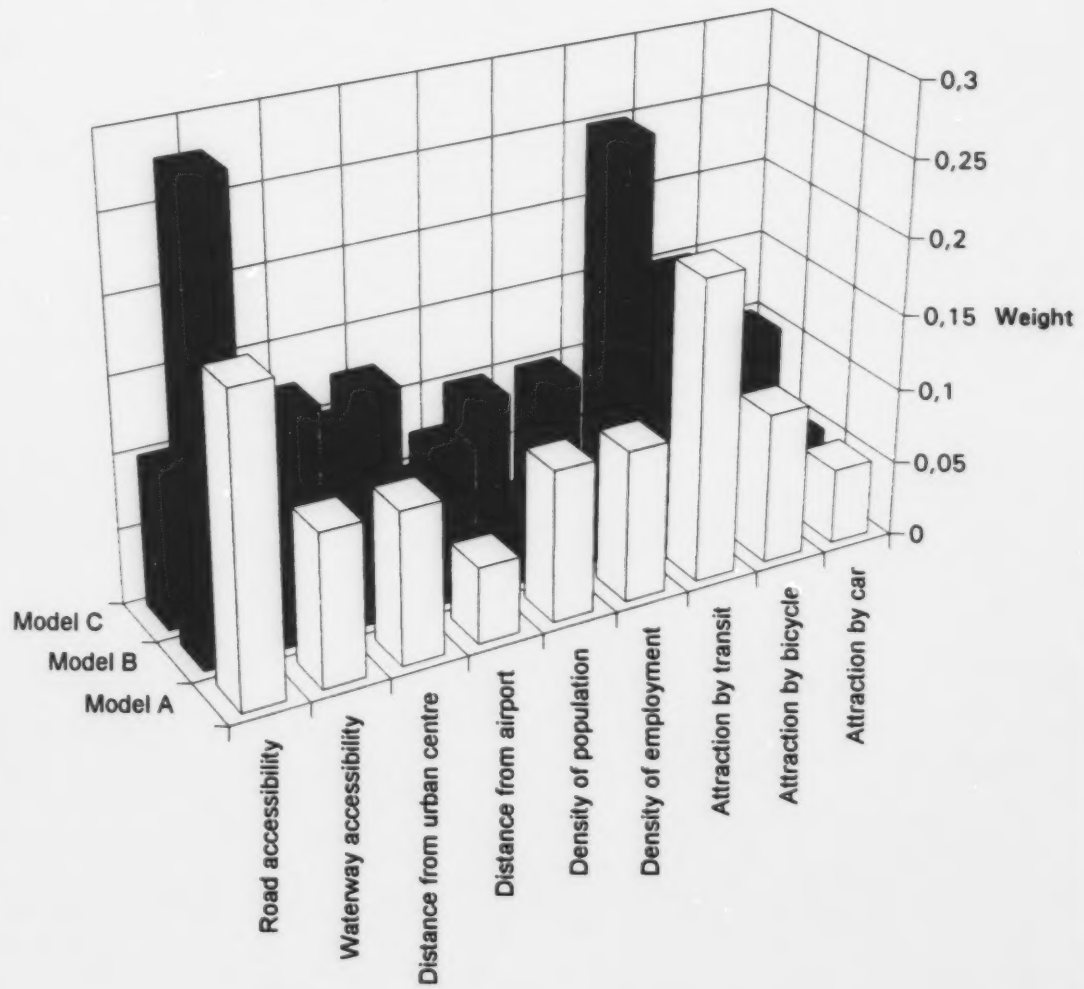


Table 4.2 : Map Layers Weights for Three Models

Map Layer	Model A w^x	Model B w^x	Model C w^x
Road accessibility (A^1)	0.2	0.3	0.1
Waterway accessibility (A^2)	0.1	0.15	0.05
Distance from urban centre (A^3)	0.1	0.15	0.1
Distance from airport (A^4)	0.05	0.1	0.05
Total Accessibility Weight	**0.45**	**0.7**	**0.3**
Density of population (E^1)	0.1	0.05	0.1
Density of employment (E^2)	0.1	0.05	0.1
Total Socioeconomic Weight	**0.2**	**0.1**	**0.2**
Attraction by transit (T^1)	0.2	0.1	0.25
Attraction by bicycle (T^2)	0.1	0.05	0.15
Attraction by car (T^3)	0.05	0.05	0.1
Total Interaction Weight	**0.35**	**0.2**	**0.50**

The distribution of weights amoung variables for the three models is heuristic. The model A is our basic assumption of the weight of each map layers in the assessment of an utility level to land use. Accessibility is the most important concept, followed by interaction and the socioeconomic level. Model B puts more weight on accessibility variables representing transportation infrastructures, that is the supply side. This is based on the assumption that the utility level of land use is more depending on the level of accumulation of transportation infrastructures. For model C, the emphasis is on the attraction potential for transit, bicycle and car modes. Is this case we assume that the utility level of land use is depending more on its capacity to attract movements.

Table 4.2 and figure 4.1 underline that the utility level of land use is not fixed, but adaptable to its perception by planners, which is consistent with our previous reasoning on the variability of usefulness. In that context, the use of a GIS can provide an environment to elaborate several alternatives (or scenarios) in the assessment of that value by changing overlay weights of layers, and even map layers themselves.

4.2 The Utility Level of Land Use in Shanghai

Using the weights of table 4.2 with equation 5, a GIS was able to produce through map overlay, three utility level maps. For instance, the utility level of model A is defined by:

$$U_i = A^1 \cdot 0.2 + A^2 \cdot 0.1 + A^3 \cdot 0.1 + A^4 \cdot 0.05 + E^1 \cdot 0.1 + E^2 \cdot 0.1 + T^1 \cdot 0.2 + T^2 \cdot 0.1 + T^3 \cdot 0.05 \quad (14)$$

The utility level range from 1 to 8, where 1 is the highest utility level for the urban area, and 8 the lowest. Maps 4.1, 4.2 and 4.3 present the geographical distribution of utility levels in Shanghai for the models. Table 4.3 shows the surface occupied by each level of utility level and figure 4.2 shows the distribution of utility levels for each model.

Utility Level of Land Use in Shanghai
Map 4.1
Model A
Map 4.2
Model B
Utility Level
1
2
3
4
5
6
7
2 km

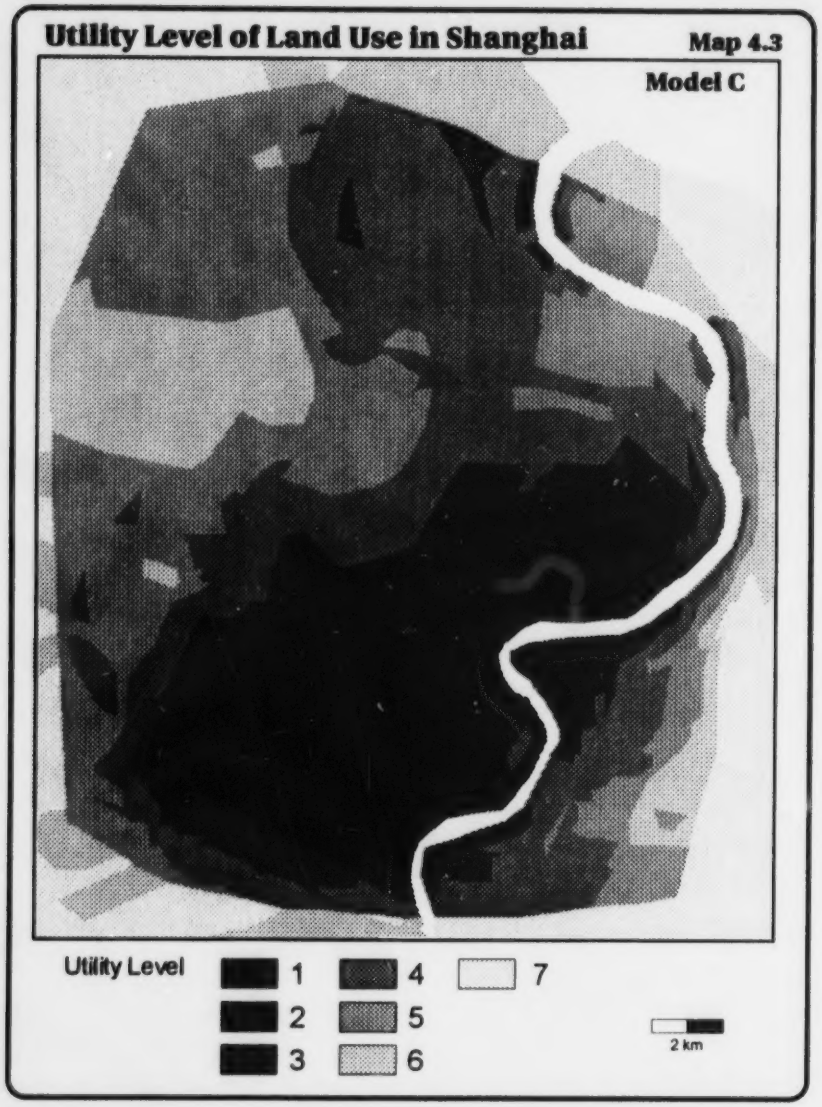

Utility Level of Land Use in Shanghai
Map 4.3
Model C
Utility Level
1
2
3
4
5
6
7
2 km

Figure 4.2: Surface Occupied by Utility Level Class

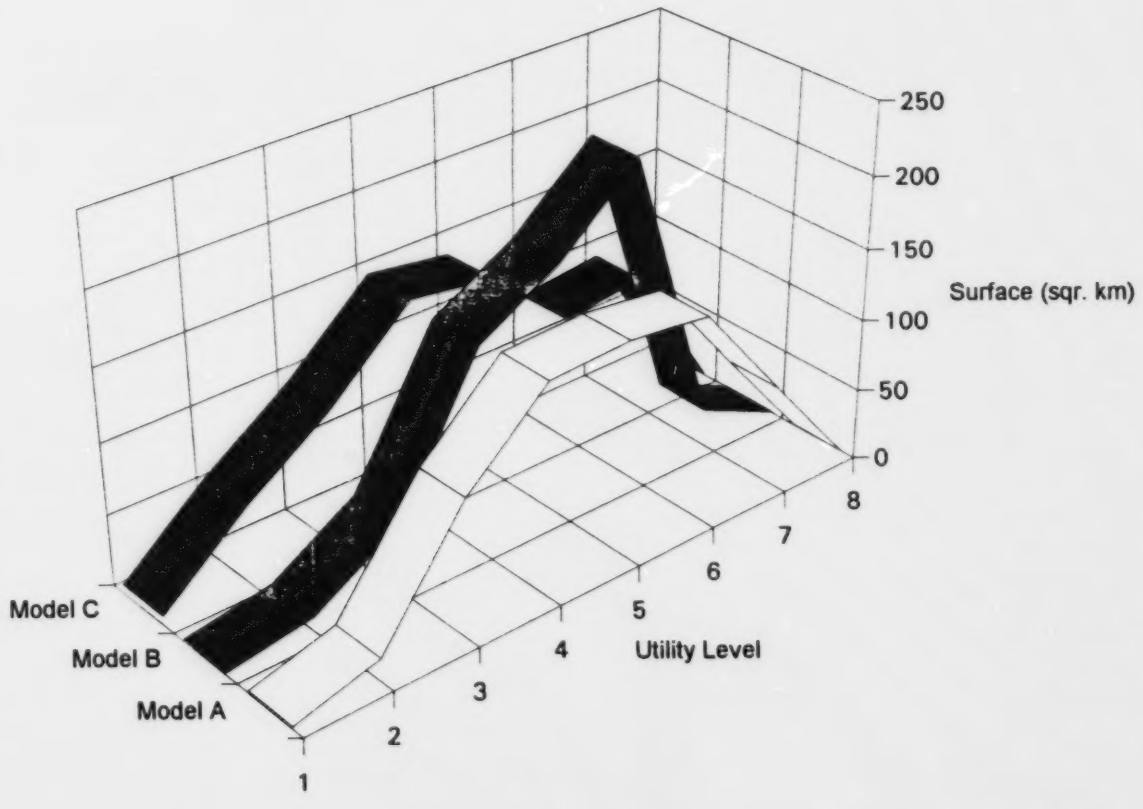


Table 4.3 : Surface Occupied by Utility Level Class

Utility Level	Model A		Model B		Model C	
	Area (KM^2)	%	Area (KM^2)	%	Area (KM^2)	%
1	1.285	0.20	1.770	0.28	6.314	1.00
2	16.713	2.65	11.085	1.76	55.975	8.88
3	97.115	15.41	46.997	7.45	97.012	15.39
4	148.714	23.59	143.743	22.80	147.953	23.47
5	151.189	23.98	175.690	27.88	139.171	22.07
6	144.170	22.87	224.949	35.68	89.016	14.12
7	71.232	11.30	26.184	4.15	94.978	15.06
8	0.039	0.00	0.039	0.00	0.039	0.00

Several preliminary conclusions can be advanced from the utility level maps. First, the highest utility levels are not near the central area of Shanghai. This tends to confirm that there is no central business district like the ones that are usually found in occidental cities. The most plausible factor explaining this is that the neighbourhoods in Shanghai are planned to be relatively self sufficient in order to limit the movements within the city. Another reason is since 1949, the chinese socialist economy did not require much office space as decisions and policies were centrally planned. Second, the three models show that the highest areas of utility level values are in the western part of the city along the Wusong river, which corresponds to an active industrial district. This reflect the status of Shanghai as a industrial production centre. Another area of high utility level corresponds to the Yangpu industrial district where the main port facilities of Shanghai are located. In a lesser extent, the Wusong industrial district as an average utility value, even if it is located far from the central area. Third, few areas have an high utility level and the distribution tend to be normal like (see figure 4.2). This means that in Shanghai a limited number of land use zones have a high number of spatial accumulation characteristics, and no zone have the optimal. Fourth, model A have the most normal-like distribution of the surface occupied by utility levels (see figure 4.2). This favours that model has the best choice of weights distribution for the available variables in the assessment of an utility level to land use in Shanghai.

In order to find the utylity level by land use type, the utility level maps were overlayed with the land use map of Shanghai and contingency coefficient were calculated.

Table 4.4 : Surface Occupied by Land Use and Utility Level Class in Shanghai, Model A.

Utility Level	Non Urban	Built Area	Industrial	Institutional	Utility	Park	Airport	Warehousing	Total
8	0.033*	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.039
	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)
7	65.349	3.955	0.000	0.000	0.000	0.000	1.892	0.037	71.232
	(10.37)	(0.63)	(0.00)	(0.00)	(0.00)	(0.00)	(0.30)	(0.01)	(11.30)
6	127.14	9.573	0.323	0.609	0.565	0.080	5.021	0.856	144.170
	(20.17)	(1.52)	(0.05)	(0.10)	(0.09)	(0.01)	(0.80)	(0.14)	(22.87)
5	119.09	14.840	5.388	1.378	1.588	1.154	7.190	0.556	151.189
	(18.89)	(2.35)	(0.85)	(0.22)	(0.25)	(0.18)	(1.14)	(0.09)	(23.98)
5	87.250	39.299	12.281	1.496	4.226	0.637	1.815	1.710	148.714
	(13.84)	(6.23)	(1.95)	(0.24)	(0.67)	(0.10)	(0.29)	(0.27)	(23.98)
3	29.004	50.246	9.357	2.070	2.989	2.205	0.098	1.146	97.115
	(4.60)	(7.97)	(1.48)	(0.33)	(0.47)	(0.35)	(0.02)	(0.18)	(15.40)
2	2.556	9.639	2.196	0.627	0.665	0.452	0.000	0.579	16.713
	(0.41)	(1.53)	(0.35)	(0.10)	(0.11)	(0.07)	(0.00)	(0.09)	(2.65)
1	0.179	0.690	0.368	0.000	0.000	0.047	0.000	0.000	1.285
	(0.03)	(0.11)	(0.06)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.20)
Total	430.61	128.25	29.91	6.18	10.03	4.58	16.02	4.88	630.46
	(68.30)	(20.34)	(4.74)	(0.98)	(1.59)	(0.73)	(2.54)	(0.77)	(100.0)

Note: The first value is the area in square kilometre, and the second is the percentage of the total area of Shanghai.

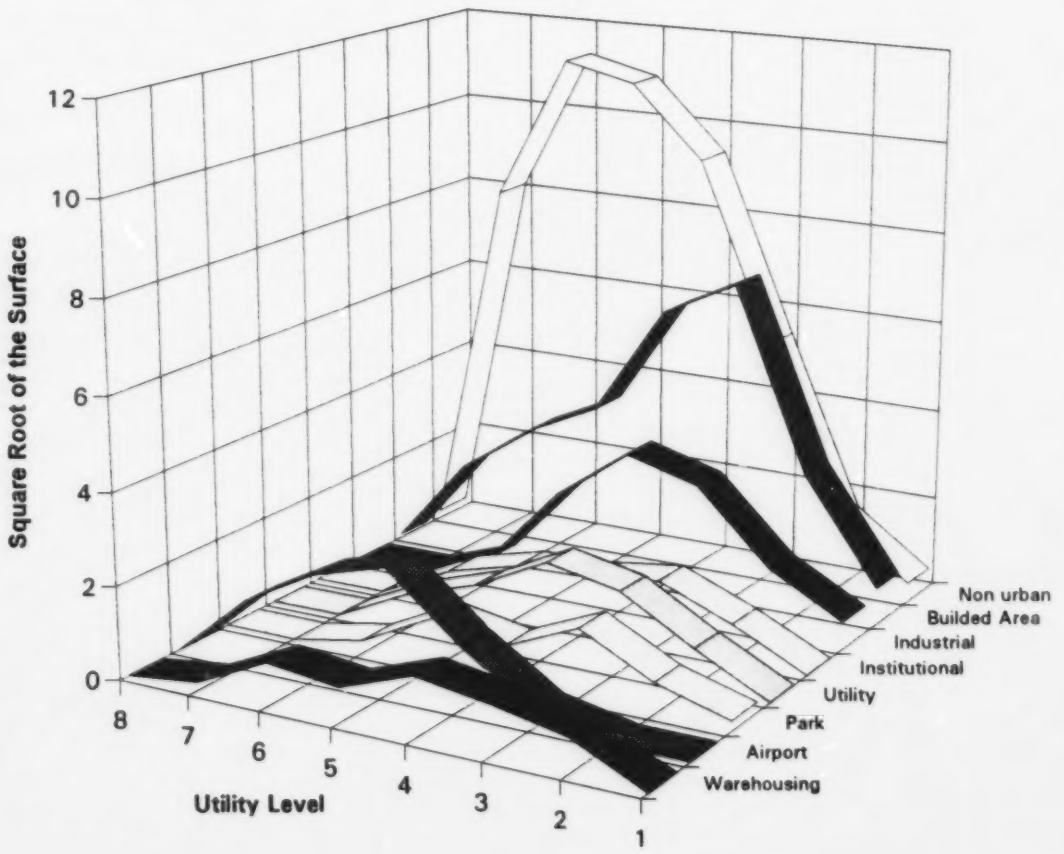
Table 4.5: Measures of Association between Utility Level and Land Use in Shanghai.

Measure	Model A	Model B	Model C
Contingency Coefficient	0.4781	0.3957	0.5009
Cramer's V	0.1721	0.1362	0.1830
Tshuprow's T	0.1486	0.1176	0.1580

Table 4.5 suggests a relationship between the utility level and the land use type with a contingency coefficient of 0.4781 for model A. Model B and C show similar contingency coefficients (0.3957 and 0.5009 respectively). Figure 4.3 illustrates that non-urban land use have lower levels of utility than urban land use. This is particularly true for the distribution of the utility level of industrial, institutional, utility and park land uses that are located in the central part of Shanghai where the concentration of economic activities, transportation infrastructures and movements is higher. Airports and warehousing, by their peripheral location have a lower utility level distribution. Parks have a surprisingly high distribution of utility level that can be explained by the fact that they are mainly located in central areas and are benefiting from the locational utility level of surrounding land uses.

The more the utility level is linked to the land use type, the more an urban system has adjusted is transportation system with its land use pattern. This means that high utility levels must correspond to specific types of land use like commercial and industrial, and that low utility levels must correspond to land use types like residential and non-urban. Small contingency coefficients in Shanghai suggest that the transportation system's supply does not respond effeciently to the mobility demand of land uses. Other measures of association like the Cramer's V and the Tschuprow's T (see table 4.5) show even less relationships in Shanghai between the utility level and land use. Therefore, the status of transportation / land use optimization in Shanghai is far from being efficient. Depending on what measure of association is considered (contingency coefficient, Cramer's V or Tshuprows' T), the level of

Figure 4.3: Utility Level by Land Use Type, Model A



transportation / land use optimization in Shanghai range from 15 to 50%, so the most plausible value is likely to be around 30%.

Comparing the results with the planning goals in Shanghai reveals inadequacies between the existing utility level of land use and the projected land use. Zones of high utility level coincide with actual industrial zones, more specifically heavy and labour intensive industrial zones. The strategic planning level of the authorities of Shanghai consist in 1) Upgrating road sections which have already reached congestion levels at their present design standards to face the potential demand from a new economic infrastructure. 2) Optimizing road and transit network for a better efficiency. 3) Changing the land use pattern of the municipality towards a more efficient spatial organization (Comtois and Rodrigue, 1991). This strategy will reorganize the land use pattern of Shanghai by establishing a hierarchical urban structure composed of the central city, satellite towns, county markets and suburban counties. The authorities plan a shift towards the light industrial sector with a more value added production and the creation of a commercial district starting from the central area and extending towards the eastern bank of the Huangpu river in a new development zone named Pudong (see map 4.4). If so, a major change in the urban structure that will change the utility level of whole districts is forecasted. This will be achieved through land use changes, population relocation, new industrial and commercial zones and the construction of two ring roads with bridges crossing the Huangpu river (one already completed and another under construction). As the existing industrial infrastructures age and the plan is progressively applied, a new pattern of utility level of land use will emerge. It is likely that the utility level of the central area of Shanghai will raise, as well as the one of the Pudong area and that the utility level of old industrial areas along the Wusong creek will drop. Is the urban structure of Shanghai in a process of change from a polynuclear state towards of a nuclear city? Other evidences suggest that the new urban structure will rather be linear because heavy investments are done along main commercial roads, especially between the central area and the international airport. Changes at an other scale are also occuring. Shanghai is in the process of integration of a vast economic space by acting as an intormodal centre and the hub of a corridor of economic development towards Hangzhou and Nanjing.

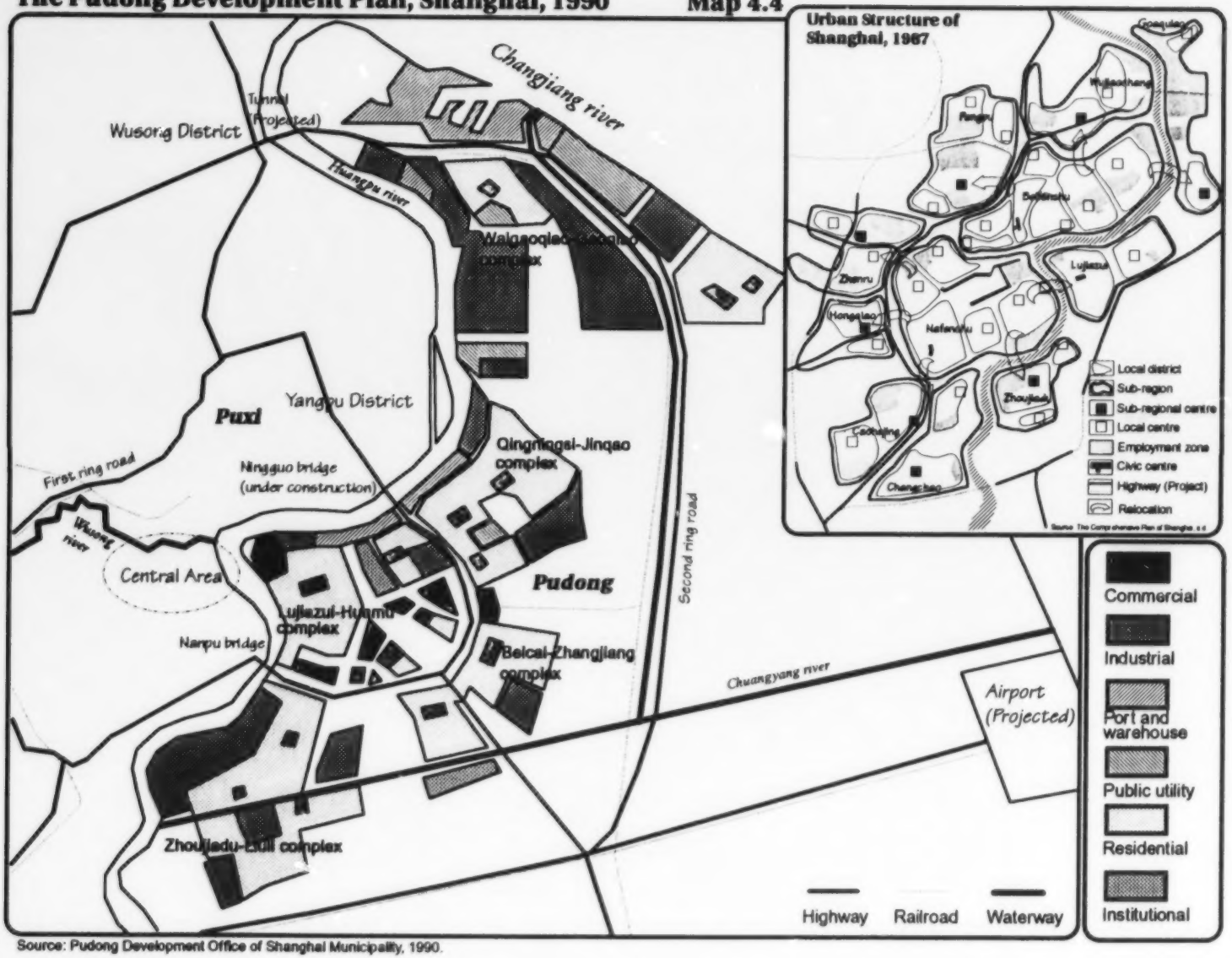
5. Conclusion

The utility value of land use is a more complete notion than the land rent theory. It illustrates general level of spatial accumulation of transportation infrastructures (accessibility level), socioeconomic activities and spatial interactions. The more a land use zone have an high utility level, the more that zone is important in the overall economic performance of an urban system. Starting from our initial definition of utility value, we have stressed the difficulty to give a monetary value by level of utility, so we have limited ourselves to the notion of utility level. In this article, an utility level axed towards the transportation supply and the spatial distribution of interactions was assessed in order to represents the socioeconomic value of land use zones in Shanghai. Areas with the highest utility level of the city are not in the central district like we would expect it in other urban areas, but in a part of the city corresponding to heavy, labour intensive industrial activities. This tend to confirm that there is no central business district in Shanghai. We must keep in mind that the utility level is a very flexible concept that depends on what is viewed as useful and on what kind of variables are used to represent it. To illustrate this, the weights that give an utility level through map overlay have been changed to produce three models of spatial distribution of utility levels.

From the aspect of transportation and land use optimization in Shanghai, the utility level enable us to point out areas where more infrastructures could be added if a raise of the utility level is required. This is likely to occur because major changes in the urban structure are forecasted. The utility level must be consistent with the land use type otherwise problems of insufficiencies of transportation infrastructures appear and the effeciency of the urban system drops. The measures of association between the utility level and the land use in Shanghai underlines the weak capacity of the transportation system to answer to transportation demand of land uses. Therefore, the relationships between transportation and land use in Shanghai are far from being efficient and measures suggest an efficiency level of around 30%. Since an efficiency level of 100% is conceptually impossible, it would be relevant to compare the utility levels and land uses of different cities to better assess what is a low efficiency level, and how high the relationship betwen the utility level and land use can go in efficient cities. However, considering the heterogeneity of available information this is not an easy undertaking.

Geographic information systems are an efficient tools to help transportation / land use planning which includes decision thinking and decision making processes. The utility level is part of a strategic and tactical planning

The Pudong Development Plan, Shanghai, 1990 **Map 4.4**



Source: Pudong Development Office of Shanghai Municipality, 1990.

process, which aims to acheive a better level of transportation / land use optimization.

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